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(54) Abstract Title

Satellite Communication Method and Apparatus

(57) A satellite (4) communicates with mobile terminals (18) within the coverage area of a beam (50) using a plurality of frequency channels. Each of the frequency channels is allocated to a group of said terminals which fall within a predetermined region (52), such that the variation of propagation delay between the satellite and each mobile terminal in the same group is restricted. Different mobile terminals in each group are allocated different TDMA slots and according to the method, interference between adjacent slots is reduced.

FIG.8

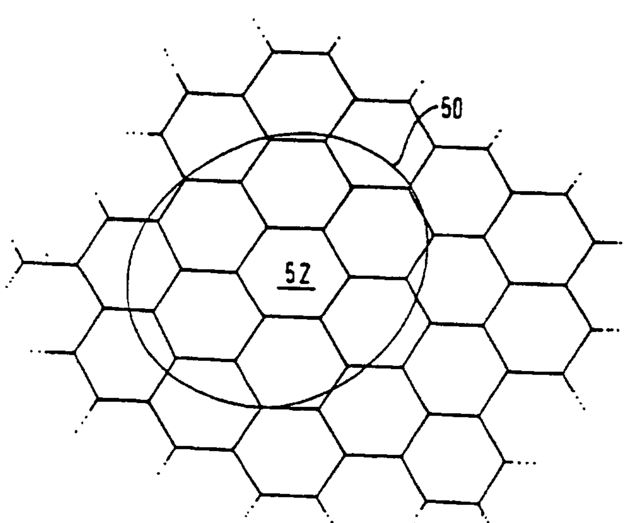

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FIG. 1

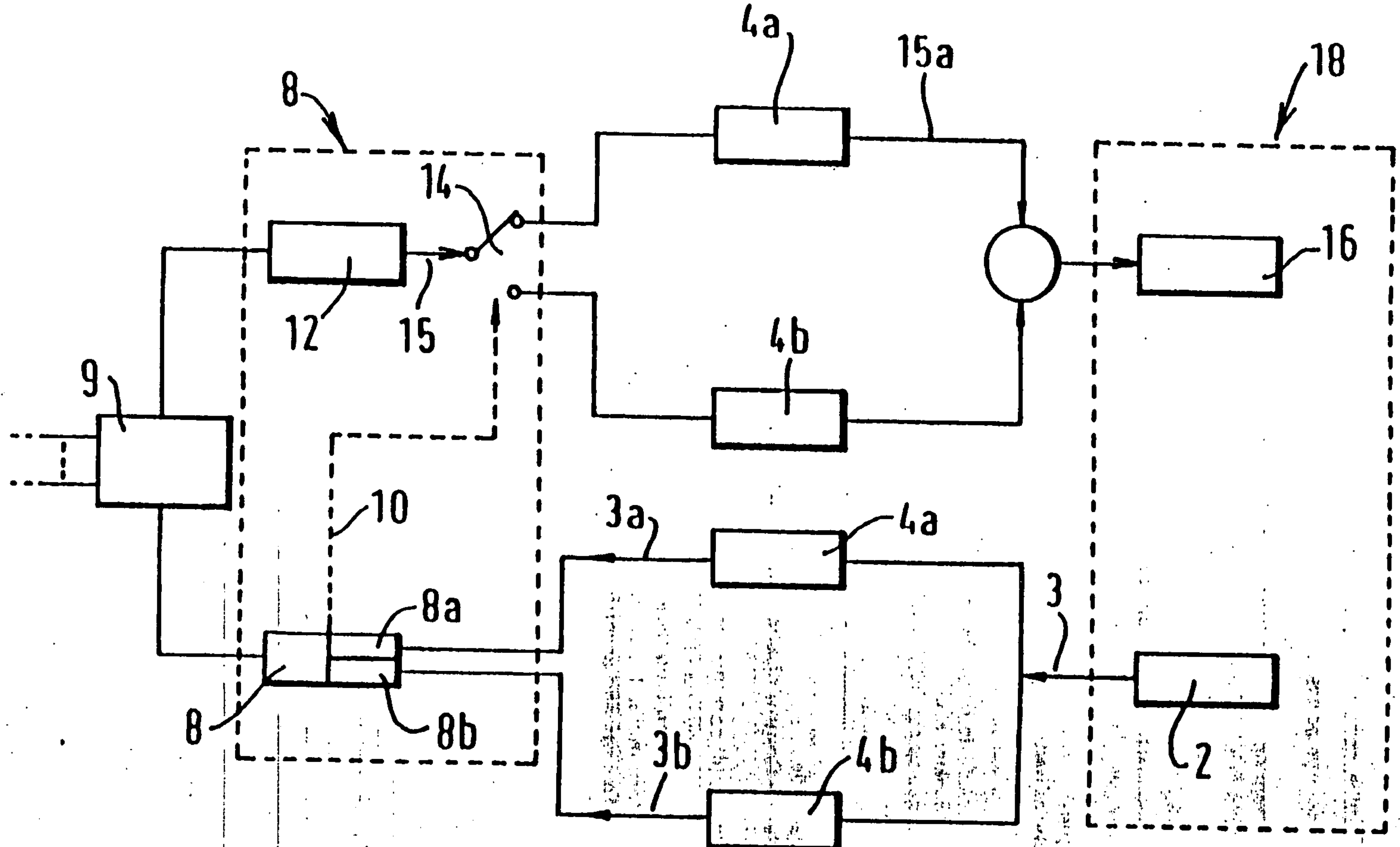


FIG. 2

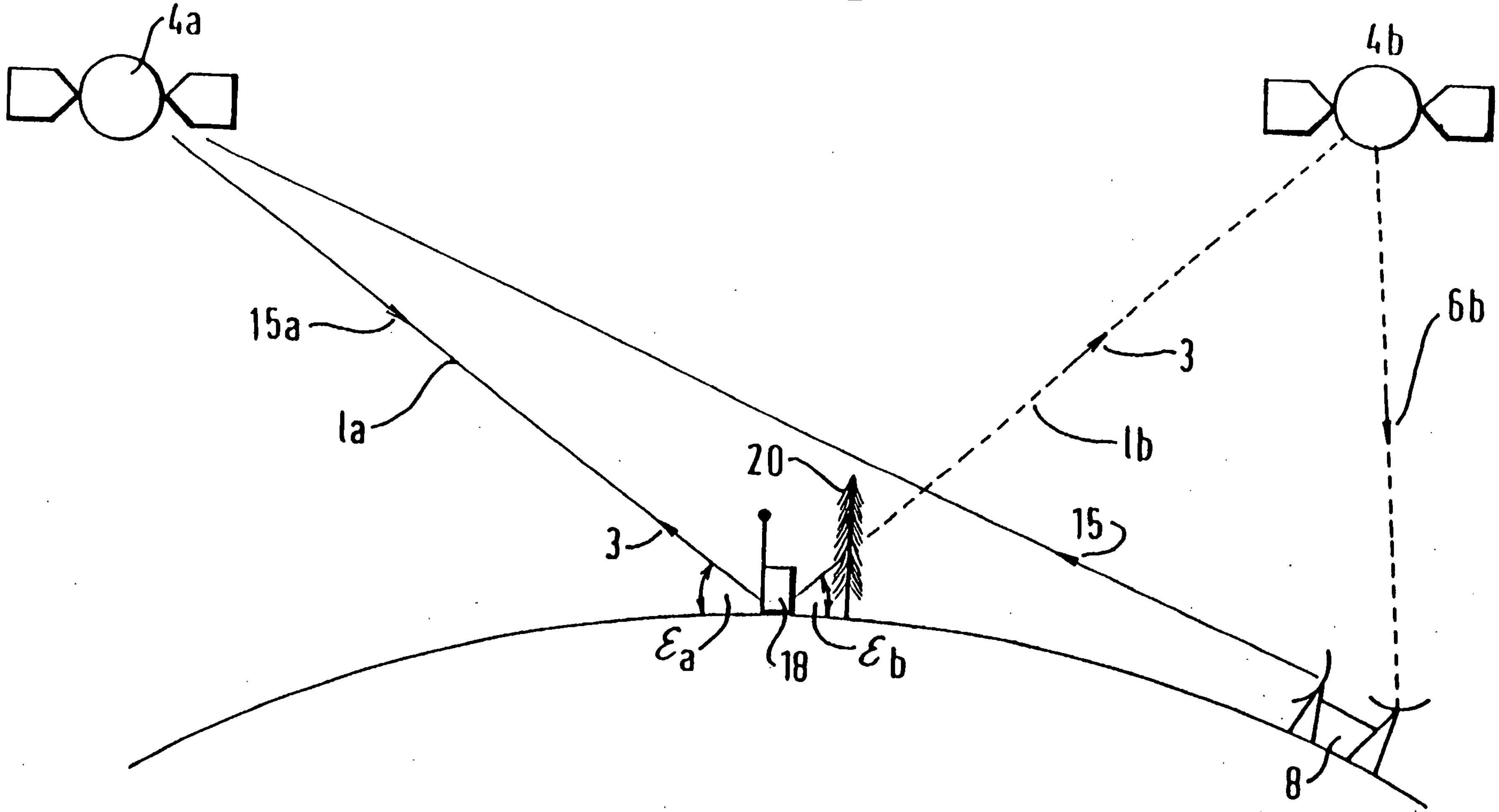


FIG. 3

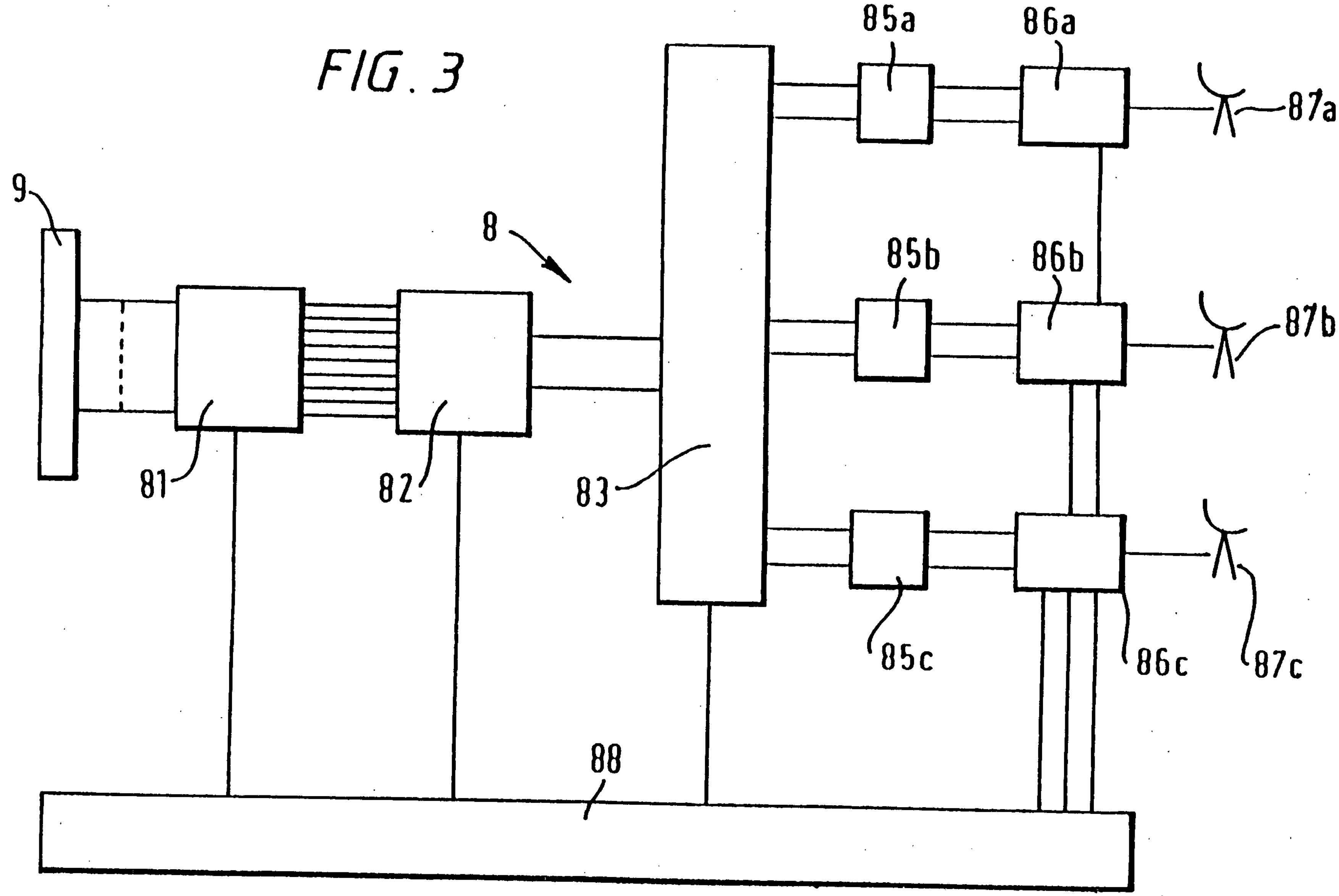


FIG. 4

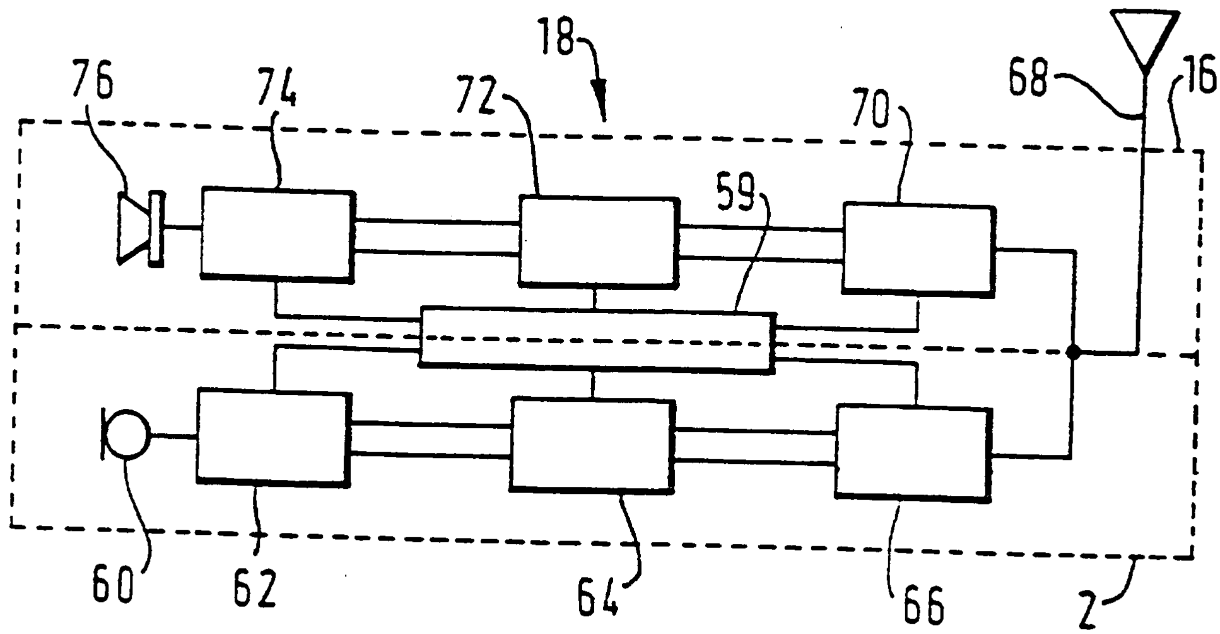


FIG. 5

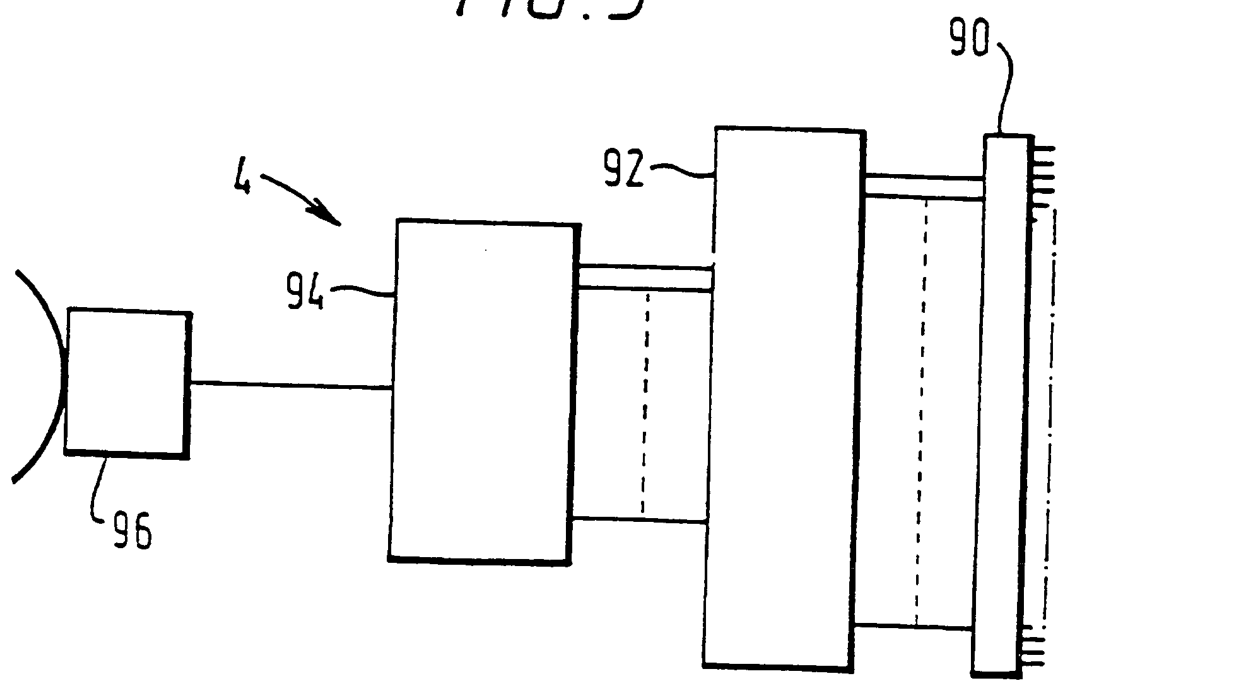


FIG. 6

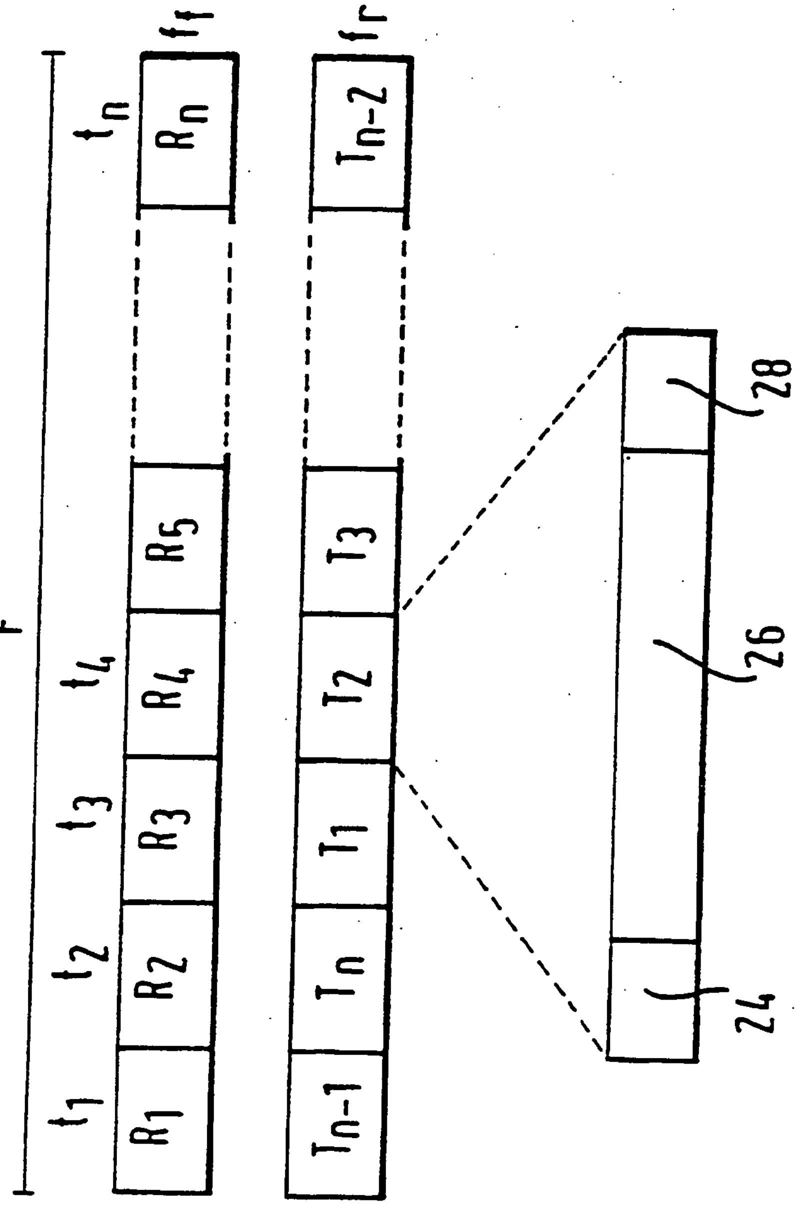
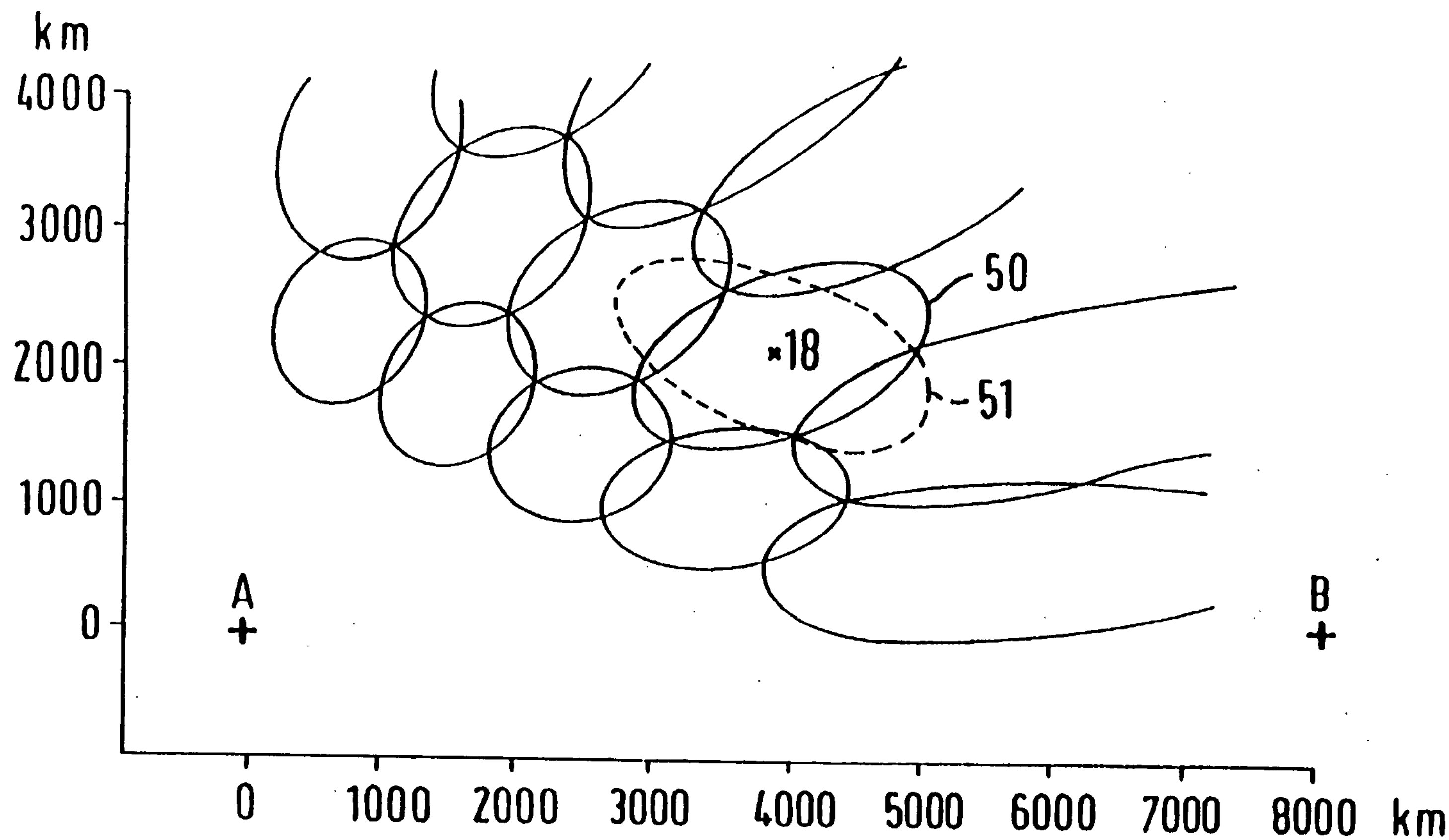


FIG. 7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4000
3000
2000
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7000
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FIG.8

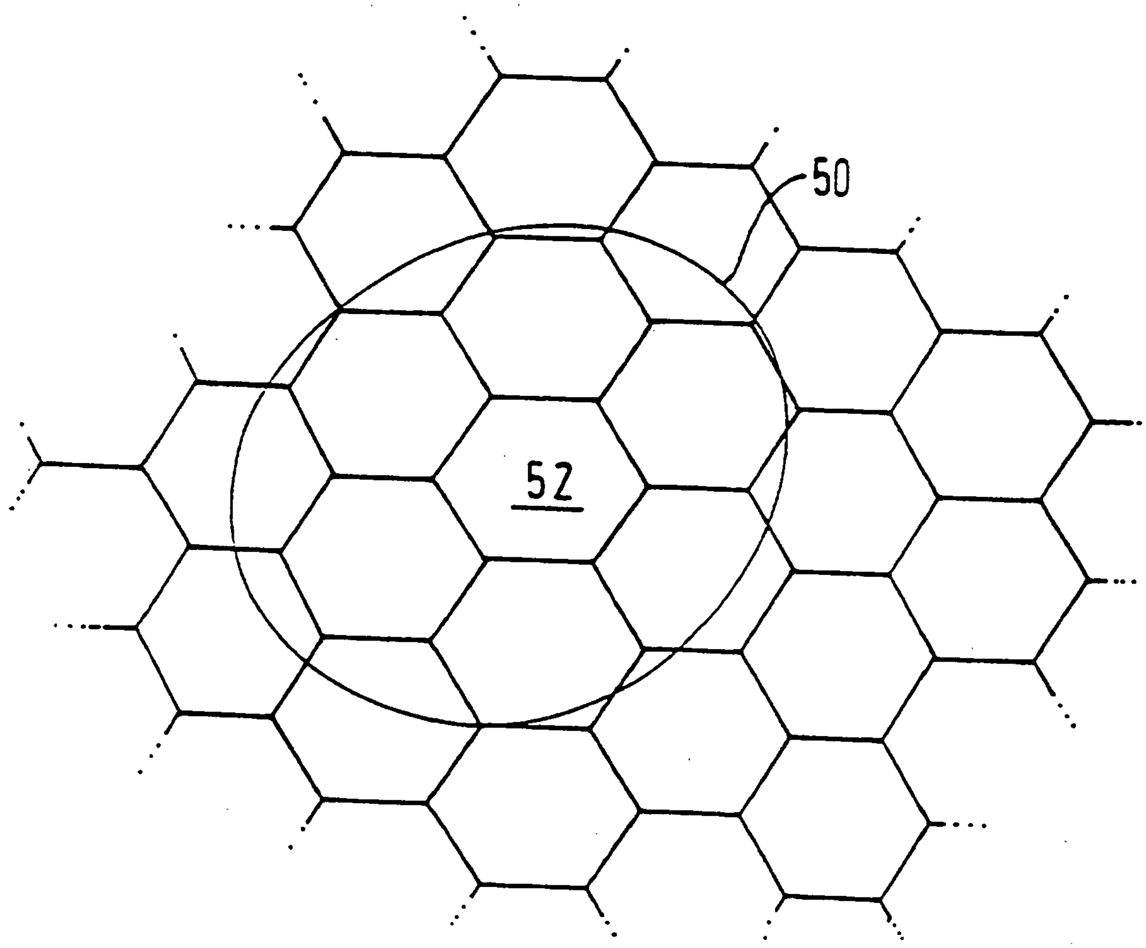
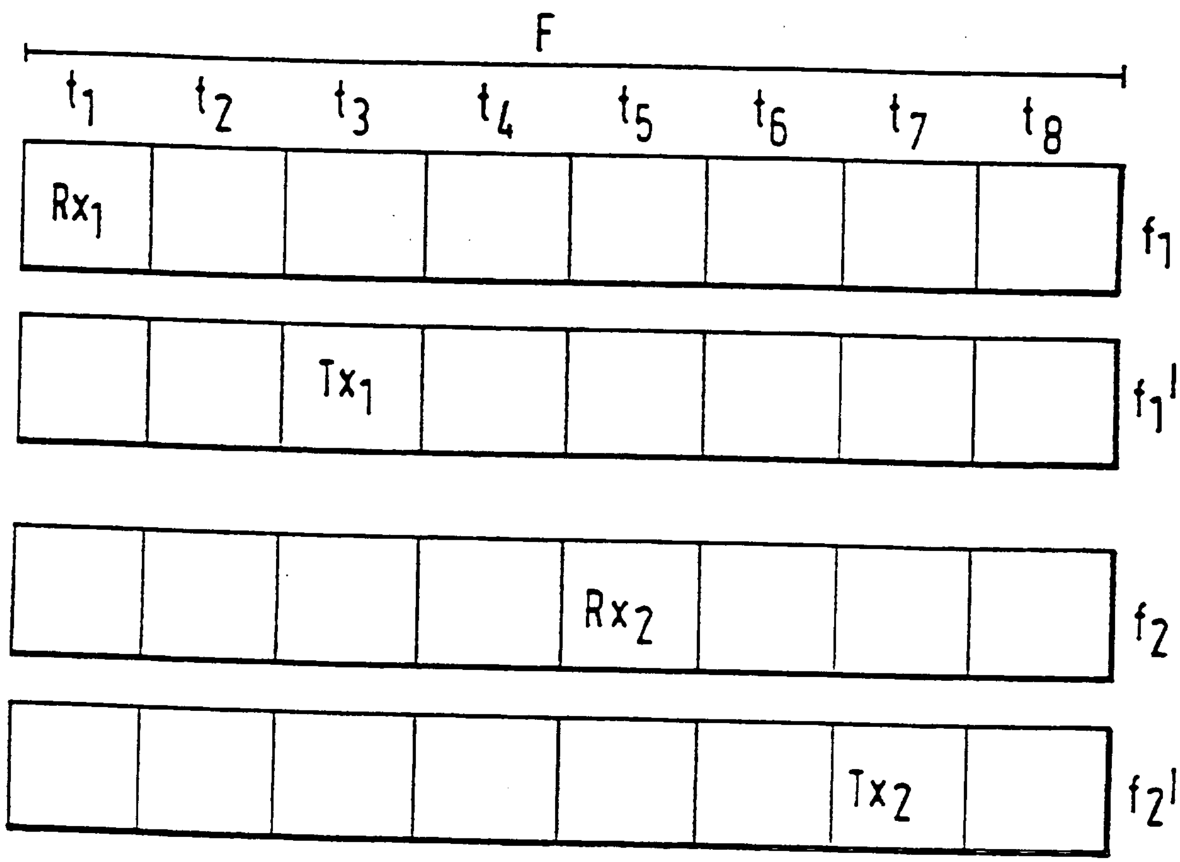


FIG. 9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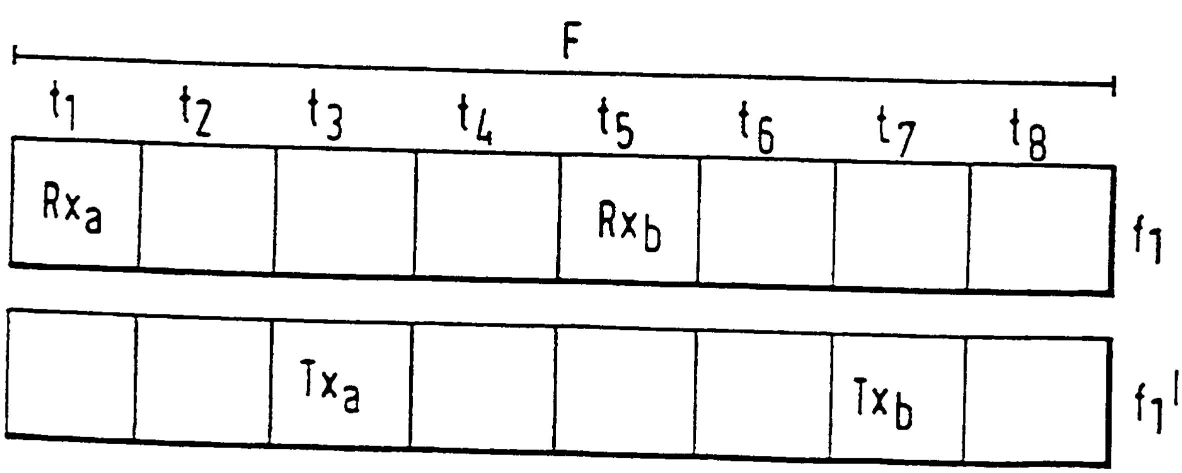
t2
t3
t4
t5
t6
t7
t8
Rx1
f1
Tx1
f1'
Rx2
f2
Tx2
f2'

FIG. 10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Rxa
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f1'

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SATELLITE COMMUNICATION METHOD AND APPARATUS

The present invention relates to a method and apparatus for communication via satellite, and in particular but not exclusively for voice or data communication using non-geostationary satellites and/or mobile terminals.

In communication systems which use non-geostationary satellites, the number and orientation of satellites in view of a ground-based terminal varies during a call. Thus, the communication link between the terminal and any one satellite may become weaker as the elevation angle of the satellite decreases and ultimately the link may become inoperable as the satellite moves out of sight of the terminal. It is therefore desirable to select another satellite for communication with the terminal, in a procedure known as "handover". The document EP-A-0 421 698 describes one such method. However, handover between satellites may result in loss of part of the signal, or sudden variations in signal quality, which are unacceptable in voice or data communications.

Furthermore, the line of sight between the terminal and a particular satellite may become obstructed by buildings, trees or other obstacles as the terminal or the satellite moves during a call. This effect is known as "blockage", and leads to

fading in the received signal.

Signal fading may also occur when a signal transmitted by a satellite is reflected off the ground or buildings and the reflected signal is received at the terminal together with the direct signal. The phase difference between the direct and reflected signals may lead to destructive interference at the terminal, so that the received signal strength is reduced. This is known as "multipath" fading.

The document WO-A-93 09578 discloses a satellite communication system in which the satellites monitor the quality of signal received from a terminal and determine which one is best suited to handle the call to the terminal. One of the satellites re-transmits the signal received from the terminal to other satellites or gateways.

The conference paper "The Globalstar Mobile Satellite System for Worldwide Personal Communications" by Wiedeman and Viterbi, 3rd International Mobile Satellite Conference, 16-18 June 1993, Pasadena, California discloses a communication system in which return link signals are received by two or three satellites; gateway stations measure the signal level or each of these alternate paths and control which signal paths are used. This system is exclusively designed for use with code-divided

multiple access (CDMA).

However, CDMA suffers from a number of drawbacks when used for mobile communications. The mobile terminals are complex, since they require a separate decoder for each satellite path. Moreover, CDMA is inefficient in frequency re-use unless the users are evenly distributed, and power levels cannot be freely varied for each user without causing interference for other users. Furthermore, at peak levels of use significant interference takes place.

According to one aspect of the present invention, there is provided a method of communication between a first earth station and a second earth station via a plurality of satellite beams, in which the second earth station receives a signal from the first earth station via each of said plurality of satellite beams, the signals from the first earth station being transmitted within a predetermined period in a repeating time frame. The satellite beams may be generated by the same satellite or by different satellites.

According to another aspect of the present invention there is provided a method for satellite communication in which a terminal transmits a signal within a predetermined period in a repeating time frame, which is received by all of the satellites in

its field of view and is relayed by all the satellites to a terrestrial station.

In this way, blockage may be reduced without the inherent disadvantages of CDMA.

The terrestrial station may either decode the best received signal or may combine all of the received signals to reduce error in the received signal. The terrestrial station may then select a forward link to the terminal through one or more of the satellites according to the signal received from them.

Thus, a smooth handover may be achieved and blockage and fading may be reduced.

In order that the selection of satellite for the forward link may be transparent to the terminal, the terrestrial station may calculate the delay in the transmission via the selected satellite and adjust the timing of its transmission accordingly so that the transmitted signal is received by the terminal in the same time slot throughout the call. The calculation may take into account both the variation in delay as the selected satellite moves relative to the earth, and the difference in delay when handing over from one satellite to another, so that the quality of communication is not impaired by handover and complex circuitry is not required in the terminal.

In addition, the terrestrial station may compensate for the Doppler shift in the signal received from the terminal and adjust the frequency of the transmitted signal accordingly so that the terminal receives a signal at a constant frequency throughout a call. The Doppler shift may be partially compensated for by the satellites.

In order to facilitate simultaneous communication with multiple users through one satellite, areas of the earth are preferably divided into a number of fixed regions, with a frequency being assigned to a terminal both for transmission and reception of signals according to the region in which the terminal is located. The locations of the regions are determined according to their positions on the earth, rather than their positions relative to the satellite. Simultaneous communication between different terminals in the same region and at the same frequencies is achieved by allocating different time slots within a repeating time frame to each of the terminals. Since the different terminals using the same frequencies are contained within a fixed region and the variation in propagation delays is therefore limited, interference between the adjacent time slots is avoided.

According to another aspect of the present invention, there is provided a method of satellite

communication in which an earth station transmits a signal in such a way that the signal is linked through a first satellite beam and is received during a first time slot in a repeating time frame and the signal is repeated such that the signal is linked through a second satellite beam and is received during a second time slot within the repeating time frame.

According to another aspect of the present invention, there is provided a method of satellite communication in which an earth station receives a signal transmitted in a first satellite beam at a first frequency during a first time slot in a repeating time frame and receives the same signal transmitted in a second satellite beam at a second frequency during a second time slot within the repeating time frame.

Thus, both blockage and multipath fading are reduced without the inherent disadvantages of CDMA. Moreover, the satellites used for this method may be comparatively simple in construction.

The signal of better quality may be decoded by the earth station, or the error rate may be reduced by comparing the two signals and deriving an improved signal from the information contained therein.

According to another aspect of the present invention, there is provided a method of communication

via a plurality of satellite beams which each carry a reference signal, in which a first earth station receives some of the reference signals, and transmits a signal indicative of which signals are received.

According to another aspect of the present invention, there is provided a method of communication via a plurality of satellite beams which each carry a reference signal, in which a second earth station receives a signal indicative of which of the reference signals are received by a first earth station. In this way, the second earth station may select the optimum beam for the forward link independently of the voice or date communication.

The present invention extends to a terrestrial station having means for performing the functions of one or more of the earth stations or terminals described above.

Specific embodiments of the present invention will now be described with reference to the accompanying drawings, in which:-

Figure 1 is a schematic block diagram of the forward and return links between an earth station and a mobile terminal;

Figure 2 is a schematic elevation showing alternative paths between the earth station and the mobile terminal;

Figure 3 is a schematic diagram of the earth station;

Figure 4 is a schematic diagram of the mobile terminal;

Figure 5 is a schematic diagram of one of the satellites;

Figure 6 is a diagram of the format of forward and return packets within a frame according to a first embodiment;

Figure 7 shows the arrangement of spot beam footprints on the earth's surface;

Figure 8 shows the arrangement of cells on the earth's surface in the first embodiment;

Figure 9 is a diagram of the format of forward and return packets within a frame according to a second embodiment; and

Figure 10 is a diagram of an alternative format to that shown in Figure 9.

FIRST EMBODIMENT

A first embodiment of the present invention will now be described with reference to Figures 1 to 8.

In Figure 1, a transmitter 2 of a mobile terminal transmits a signal 3. The mobile terminal has a substantially omni-directional antenna, so that the transmitted signal 3 is received by a first satellite 4a and a second satellite 4b in view of the mobile

terminal. The signal 3 is retransmitted from each satellite 4a, 4b as separate signals 3a and 3b. These signals 3a and 3b are received by an earth station 8 having first and second receivers 8a and 8b for receiving signals from the first and second satellites 4a and 4b respectively. In this embodiment, the earth station 8 has first and second directional antennas directed towards the first and second satellites 4a, 4b respectively. Thus, the same information is received twice by the earth station 8 in the separate signals 3a and 3b. The earth station 8 may therefore select the better of the two signals 3a and 3b, e.g. the one with the lowest error rate, for conversion to a telephone signal to be passed to a public service telephone network (PSTN) 9. Alternatively, if both signals contain errors, data may be derived from both signals to provide a combined signal with fewer or no errors. The combined signal is then converted and sent to the PSTN 9.

The earth station 8 also analyses the received signals 3a and 3b to determine which is of better quality. Since there is a strong correlation between the strength of a return link from one of the satellites 4a, 4b and the strength of a forward link to the portable transmitter 2 through the same satellite 6a, 6b, the earth station 8 selects one of

the satellites 6a, 6b for the forward link to the portable transmitter 2 and generates a selection signal 10.

When a signal is received from the PSTN 9 for transmission to the portable terminal 2, the signal is passed to a transmitter 12 in the earth station. The transmitter 12 selects one of the satellites 4a, 4b, as shown schematically in Figure 1 by a switch 14, in response to the selection signal 10. In this case, the first satellite 4a is selected as the most suitable for the forward link. The transmitter 12 then transmits a signal 15 to the first satellite 4a, which retransmits the signal as a signal 15a to a receiver 16 of the mobile terminal. The transmitter 2 and the receiver 16 may be connected to the same antenna on the mobile terminal, or to separate antennas. In both cases, the receiving antenna is omni-directional and therefore may receive signals from either of the satellites 4a, 4b. Thus, the receiver 16 receives a signal 15 through the stronger link.

A situation in which blockage occurs will now be described with reference to Figure 2. This figure shows a section of the earth's surface on which the earth station 8 and a mobile terminal 18 are located. The first and second satellites 4a, 4b are within the

line of sight of both the earth station 8 and the mobile terminal 18. The angle of elevation ϵ_b of the second satellite 4b relative to the mobile terminal 18 is greater than the angle of elevation ϵ_a of the first satellite 4a and the path distance between the earth station 8 and the second satellite 4b, and between the second satellite 4b and the mobile terminal 18 is shorter.

However, in this case the mobile terminal 18 is positioned close to a tall obstacle 20 such as a tree, which obscures the line of sight 1b between the mobile terminal 18 and the second satellite 4b. Thus, when the mobile terminal 18 transmits a signal 3, this signal 3 is only weakly received by the second satellite 4b and thus the retransmitted signal 6b is more likely to contain errors. The earth station selects the first satellite 4a as providing a better forward link and transmits the response signal 15 only to the first satellite 4a. This response signal is retransmitted as signal 15a to the mobile terminal 18. Since the line of sight 1a between the first satellite 4a and the mobile terminal 18 is not obscured, the response signal is received strongly by the mobile terminal 18. The mobile terminal 18 does not need to select from which satellite 4a, 4b it is to receive the response signal 15a, since this is decided at the

earth station 8. Selection of the satellites 4a, 4b is therefore transparent to the mobile terminal.

If, on the other hand, the mobile terminal 18 were to move such that the obstacle 20 no longer obstructs the line of sight 1b, then the earth station 8 may receive a better signal from the second satellite 4b and will therefore select the second satellite 4b for the forward link.

When different frequencies are used for the forward and return links, and the fading is due to multipath interference, there may not be a strong correlation between the quality of forward and return links. In this case, the mobile terminal 18 transmits information to the earth station 8 relating to the strength of the signal received by the terminal 18 from the earth station 8. If the earth station 8 receives a good return link signal from the first satellite 4a but information transmitted by the mobile terminal 18 indicates that fading is occurring on the forward link, the earth station 8 may then select the satellite from which the next best signal is received for the forward link. In a case where each satellite generates several overlapping beams for communication with mobile terminals at different frequencies, the earth station 8 selects instead a different beam generated by the first satellite.

The operation of the mobile terminal 18 and the earth station 8 will now be explained with reference to Figures 3, 4, and 5.

EARTH STATION

In this example, analogue speech signals are received at the earth station 8 from the PSTN 9 for transmission to the mobile terminals 18. As shown in Figure 3, the analogue speech signals are digitized and encoded by a codec 81 and the encoded speech is converted into a series of discrete packets at a multiplexer/demultiplexer 82.

The transmission of the packets is controlled by a controller 88 which selects which satellite 4 is to be used for the forward link on the basis of the quality of signal received from each satellite 4. The controller 88 controls a selector 83 to send each packet to one of a plurality of buffers 85a, 85b, 85c. The timing of the output of each buffer 85 is controlled by the controller 88. The packets output from the buffer 85a, 85b, 85c are radio frequency modulated by corresponding RF modulators/demodulators 86a, 86b, 86c, the frequency of modulation being controlled by the controller 88. The RF signals are modulated in different frequency bands selected by the controller 88 according to a selected beam of the satellite 4 in which the signals are to be re-

transmitted to the mobile terminal 18. The RF signals are transmitted by directional antennas 87a, 87b, 87c which are each directed towards a corresponding satellite 4a, 4b, 4c.

Each directional antenna 87 also receives signals transmitted from mobile terminals on the return link from the corresponding satellite 4, which are radio frequency demodulated by the RF modulators/demodulators 86 to form received packets. The received packets are buffered by the buffers 85 and selected by the selector 83. The series of packets is separated in channels by the multiplexer/demultiplexer 82 and decoded by the codec 81 which may also perform error checking by comparing packets received from the same mobile terminal 18 via different satellites 4. The resultant analogue signals are sent to the PSTN 9 on different lines.

MOBILE TERMINAL

As shown in Figure 4, each mobile terminal 18 includes a microphone 60 in which speech is converted into analog signals. The analog signals are converted to digital signals by an A/D converter 62 and the digital signals are encoded to form the packets by a coder 64. The coded packets are RF modulated by an RF modulator 66 for transmission from an omnidirectional aerial 68.

Signals received through the aerial 68 are RF demodulated by a demodulator 70 as received packets. The received packets are then decoded by a packet decoder 72 to form digital speech signals which are converted to analog speech signals by a D/A converter 74. The analog signals are output to a loudspeaker 76 to produce audible speech. The operation of the mobile terminal 18 is controlled by a control unit 59, such as a microprocessor and/or DSP device, which is connected to additional conventional handset components such as a key pad (not shown).

SATELLITE

Referring to Figure 5, each satellite 4 includes an antenna 90 and a beam-forming device 92, which may be a radiating array antenna and a large Butler matrix as disclosed in British Patent application no. 9407669.2 (incorporated herein by reference). The beam-forming device 92 converts signals from each element of the array into signals from a plurality of beams and vice versa. Signals received by the antenna 90 from the mobile terminals 18 are fed via a control unit 94 to an antenna 96 which retransmits the signals towards the base station in a frequency band corresponding to the beam in which the signals were received. The antenna 96 may be steered towards the earth station 8. Likewise, signals received from the

antenna 96 from the earth station 8 are redirected to one of the beams of the antenna 90 according to the frequency band in which the signals are transmitted from the earth station 8.

For the sake of clarity, a single antenna 90 and beam-forming device 92 are shown. However, since different carrier frequencies are used for the forward and return links, separate receiving and transmitting antennas 90 and beam-forming devices 92 will normally be used.

SIGNALLING FORMAT

As shown in Figure 6, the earth station 8 can communicate with a number of mobile terminals 18 at the same time by sending packets R_1 to R_n sequentially in a repeating time frame F, the beginning of which is marked by a frame header signal. Each frame F is divided into a number of time slots t_1 to t_n corresponding to different channels, each channel being assigned to one of the mobile terminals 18 by the earth station 8 when a call is set up.

For example, if the mobile terminal 18 has been assigned to the first channel, it will decode only the packet R_1 in the first slot t_1 in each frame F to generate a voice signal. The method of multiplexed communication is known as Time Divided Multiple Access, or TDMA.

A channel is assigned to each mobile terminal 18 during call setup by transmitting an instruction signal to the mobile terminal 18 from the earth station 8.

Each mobile terminal 18 is assigned a return channel having a predetermined time slot t, different from that of the forward channel, in the frame F, for transmission of a return packet T_1 to T_n. For example, the mobile terminal 18 to which the first slot t_1 is assigned for reception of the packet R_1 may be assigned the third slot t_3 for the transmission of a return packet T_1. Different frequencies f_f and f_r are used for the forward and return channels so that the mobile terminals 18 communicate in full duplex mode.

Alternatively, a half duplex mode could be used, in which the return packets T would be transmitted at the same frequency as the forward packets R, with the forward packets R alternating with the return packets T in the frame F.

Each forward and return packet consists of a header portion 24 containing control information, speech data 26 and a check portion 28 for correcting errors in the speech data 26.

In order to ensure that the correct signal is received by each mobile terminal 18, in the same time slot t in every frame F, the earth station 8 delays

the timing of transmission from the buffers 85 to a particular satellite to compensate for the variations in propagation delay via another satellite, and for the change in delay in handing over from one satellite to another. In order to determine the correct timing, the controller 88 of the earth station 8 may include a store unit storing ephemerides of the positions of the different satellites so that their position and range may be calculated at any instant. In addition, the position of each mobile terminal 18 is determined. This may be achieved by comparing the delays in the signal 3a, 3b transmitted from the mobile terminal 18 by different satellites 4a, 4b. However, this method requires that the signals 3 are received from more than one satellite if an unambiguous measurement is to be achieved. Because of blockage, this may not be possible. Hence, additional position determining methods should be used.

As each satellite 4a, 4b generates an array of beams at different angles, the angular position of the mobile terminal 18 relative to a satellite is determined by identifying the beam in which the return signal 3 is detected. In addition, the Doppler shift of the signal 3 is measured to determine the angle of the mobile terminal 18 relative to the direction of motion of the satellite. The position of each mobile

terminal 18 is calculated by some or all of the above techniques.

The earth station 8 may store the last known position of each mobile terminal 18, so that position calculation need only be carried out if the mobile terminal 18 is not found in its previous area.

The timing of transmission of the return packets T is synchronized by the mobile terminal 18 with the timing of the reception of the forward packets R. Since the earth station 8 controls the timing at which the forward packets 12 are received, the timing of the mobile terminal 18 is controlled by the earth station 8. To allow some margin for timing error, the time slots are separated by short intervals, called "guard bands".

Furthermore, the controller 88 of the earth station 8 measures the Doppler shift of the signal 3 received from each mobile terminal and controls the modulation frequency of the RF modulators 86 to compensate for the Doppler shift, so that the signal 15a is always received by the mobile terminal 18 at the assigned frequency. By the above compensatory techniques, which are carried out at the earth station 8 the processing burden on the mobile terminals 18 is reduced so that their reliability may be increased, their construction may be substantially simplified and

they may be manufactured at low cost.

More than one satellite may be selected for the forward link, the signal 15 from the earth station 8 being transmitted to each selected satellite with a timing calculated so that the signals 15a,15b from the satellites 4a,4b arrive simultaneously at the mobile terminal 18.

BEAM ARRANGEMENT

Each satellite 4a, 4b has an array antenna 90 for communication with the mobile terminal 18 which synthesizes a number of overlapping spot beams each having a projected area 50 on the earth's surface of between 1000km and 3000km in diameter, as shown in Figure 7. In Figure 7, the nadir of the satellite 4a on the earth's surface is shown at point A and the nadir of the satellite 4b is shown at point B, with the great circle distance between these points being represented by the horizontal axis. The vertical axis represents distance along a great circle orthogonal to the great circle connecting the nadirs of the two satellites 4a, 4b. The mobile terminal is located within the footprint 50 of one spot beam of the satellite 4a and within the footprint 51 of a spot beam of the satellite 4b, so that communication is possible via either satellite.

FIXED REGIONS

As shown in Figure 8, the area of the earth's surface is divided by the controller 88 into regions 52 and a pair of transmission and reception frequencies is assigned to each region 52. Thus, the transmit and receive frequency for each mobile terminal 18 are determined according to the region 52 in which it is located, the regions 52 being fixed relative to the earth's surface. A sample spot beam footprint 50 is shown overlapping a group of regions 52, which are hexagonal in this example.

When a call is set up, the position of the mobile terminal 18 is determined by the controller 88 of the earth station 8 according to the techniques described above and a control signal is transmitted to the mobile terminal 18 to assign a particular pair of frequencies. These frequencies remain unchanged throughout the call unless the mobile terminal 18 itself moves into another cell 52. Each cell 52 has a radius of approximately 200-300km, so the mobile terminal 18 is unlikely to move frequently between cells 52 during a call.

All of the mobile terminals 18 within the same cell 52 transmit and receive at the same pairs of frequencies f_f and f_r, and the signals from the different mobile terminals 18 are separated using TDMA, as shown in Figure 6. Since the different

mobile terminals 18 are contained within the relatively small, fixed area of the cell, the variation in the uplink propagation delay between different mobile terminals and any one satellite is limited. In this way, the problem of interference between signals in adjacent time slots is avoided.

The assignment of regions 52 to spot beams is determined at the satellite 4 or at the earth station 8 so that handover of regions 52 between spot beam areas 50 is transparent to the mobile terminal 18. Likewise, the handover of regions between satellites 4a, 4b is determined by the controller 88 of the earth station 8.

The spot beams are steered to the centre of a group of regions in order to improve power and spectral efficiency. In this way, each region within a group is handed over between spot beam area 50 simultaneously, with the previous spot beam being rapidly redirected to the next group of regions. Since each region is covered by a spot beam from more than one satellite, as described above, handover of regions between spot beam areas 50 may be achieved without loss of communication.

Alternatively, the spot beam areas may sweep continuously over the regions 52.

In another alternative, the assignment of

frequencies to regions may change in a predetermined sequence (so-called "frequency hopping").

SECOND EMBODIMENT

A second embodiment will now be described with reference to Figures 1 to 5, 9 and 10. The second embodiment differs from the first embodiment in the operation of the earth station 8, mobile terminal 18 and satellites 4, in that the mobile terminal 18 receives signals from different satellites 4 in different time slots.

SIGNALLING FORMAT

As shown in Figure 9, the mobile terminal 18 communicates with the earth station 8 during allocated time slots t within a repeating time frame T, via the first and second satellites 4a, 4b, or via first and second beams of one satellite, in half-duplex mode at pairs of frequencies f_1, f_1' and f_2, f_2' respectively.

In the example shown, the earth station 8 transmits a packet Rx_1 in time slot t_1 via the first satellite 4a, which packet is received at frequency f_1 by the mobile terminal 18. The mobile terminal 18 then transmits a packet Tx_1 in time slot t_3 at the frequency f_1' via a beam generated by the satellite 4a. The earth station 8 transmits a packet Rx_2, containing the same information as the packet Rx_1, via the second satellite 4b, or via a further beam generated by the

satellite 4a, which retransmits the packet Rx_2 to the mobile terminal 18 at frequency f_2 in time slot t_5. The mobile terminal 18 then transmits a packet Tx_2, containing the same information as the packet Tx_1, in time slot t_7 at the frequency f_2'. The packet Tx_2 is retransmitted to the earth station 8 by the second satellite 4b. In this way, the controller 59 has sufficient time to retune the RF modulator 66 or demodulator 70 during the intervening time slots.

When the mobile terminal has received both the packets Rx_1 and Rx_2, the packet decoder 72 combines the two, or selects the better packet, for conversion to speech, as in the first embodiment. Similarly, the earth station 8 combines the two transmitted packets Tx_1 and Tx_2 or selects the better packet, to improve the quality of the signal transmitted to the PSTN 9.

In this example, each time frame T comprises eight time slots t, so that eight mobile terminals 18 can communicate with the earth station 8 at the frequencies f_1, f_1', f_2 and f_2' using TDMA. However, the allocation of time slots is flexible, to optimize the number of users and quality of communication. During call set-up, the mobile terminal 18 monitors pilot signals transmitted by the satellites 4 to determine which satellites are in view and whether any satellite links are blocked. This information is

transmitted to the earth station 8. If only one satellite is in view, the earth station 8 allocates only one time slot for transmission and one for reception at the pair frequencies corresponding to that satellite. The mobile terminal 18 monitors the pilot signals during the calls so that, if another satellite comes into view, the mobile terminal 18 communicates this information to the earth station and further transmit and receive time slots are allocated at the pair of frequencies corresponding to the other satellite. Although in the above example two time slots are allocated for transmission by the mobile terminal 18, only one of the time slots may be used if the return link is satisfactory in order to conserve power and reduce electromagnetic emissions. This is particularly important for hand-held mobile terminals.

The controller 59 of the mobile terminal 18 monitors the quality of signal received from both satellites 4a and 4b and normally transmits only during the time slot and at the frequency corresponding to the satellite from which the stronger signal is received. However, if the selected return link provides only a weak signal, as in the case of multipath fading, the earth station 8 communicates this information to the mobile terminal 18 and the alternative return link is selected.

Furthermore, if a greater number of users is to be accommodated at any time, only one time slot for each of transmission and reception may be allocated to each mobile terminal 18.

If none of the satellites provides a link of satisfactory quality, a lower baud rate is selected and the voice data is divided into two different packets in each time frame. As shown in Figure 10, the frequencies f_1, f_1' are used for communication via only the first satellite 4a. The voice data encoded in a single packet Rx_1 or Rx_2 in the embodiment shown in Figure 9 is divided between two packets Rx_a and Rx_b which are transmitted at the frequency f_1' by the earth station 8 at half the normal baud rate in time slots t_3 and t_5 respectively. Likewise, the voice data transmitted by the mobile terminal 18 is divided between two packets Tx_a and Tx_b in each time frame T and transmitted in time slots t_2 and t_6 at half the normal baud rate. The reduction of baud rate reduces the probability of bit errors. Alternatively, two satellite beams may be used for transmission and reception, and the packets Rx_a, Rx_b and Tx_a, Tx_b may be divided between the two beams.

The above technique of selecting a lower baud rate and dividing the transmitted signal into two or more packets may also be employed in the first

embodiment.

In the second embodiment, the satellite beams are not steered but sweep across the earth's surface at a constant rate as the satellite 4 progresses in its orbit. As in Figure 7, the beams overlap so that the mobile terminal 18 is able to communicate via more than one beam at least some of the time. Furthermore, beams from different satellites 4a, 4b may overlap so that the mobile terminal 18 is able to communicate via more than one satellite 4a, 4b. Transmission or reception frequencies are allocated according to the spot beam in which the mobile terminal 18 falls and not according to the position of the mobile terminal 18 on the earth's surface. Thus, the mobile terminal can select which of the overlapping beams is used for transmission or reception by selecting the corresponding frequency, and the satellites 4 may be simplified.

The timing of forward link transmissions is controlled by the earth station 8 and the return link transmissions are synchronized with the reception of forward link signals, as in the first embodiment. However, in the second embodiment the mobile terminals 18 adjust the frequency of transmission on the return link to compensate for Doppler shift detected in the received signals, as well as the earth station 8

compensating for Doppler shift on the forward link.

Since the mobile terminals 18 using the same transmission frequency are no longer confined to a fixed region, the guardbands between time slots at the mobile terminal transmission frequencies are larger in the second embodiment, to avoid interference between adjacent time slots on the return link.

Although the above embodiments have been described with reference to a mobile or portable (e.g. hand-held) terminal, transportable or even fixed terminals may be used in the same communications system.

The system is not restricted to any particular constellation of satellites, but may advantageously be applied to satellites in low earth orbits of less than 2000 km altitude or medium earth orbits of between 10,000 and 20,000 km altitude.

In both embodiments, the number of time-slots in each time frame may be chosen according to the likely density of users. Although different frequencies are used by the mobile terminals for transmission and reception in the preferred embodiments, a single frequency may be used, with alternate time slots assigned for transmission and reception.

The embodiments are described above for illustrative purposes only and the present invention is not limited in scope thereto.

CLAIMS:

1. A method of communication between a base station and a plurality of user stations each of which is located within the coverage area of a beam generated by a satellite, said beam carrying a plurality of frequency channels,

said method comprising allocating each of said frequency channels to a respective group of said user stations which fall within one of a plurality of predetermined regions within the beam such that the variation in propagation delay to said satellite among said group of said user stations is limited, and communicating between the base station and said user stations within said beam in said allocated frequency channels.

2. A method as claimed in claim 1, wherein said group comprises ones of said user stations which are approximately equidistant from said satellite.

3. A method as claimed in claim 2, further comprising determining the positions of the user stations relative to the earth's surface and allocating each of said frequency channels according to the determined positions of the user stations.

4. Apparatus for communication with a plurality of user stations which are located within the coverage area of a beam generated by a satellite, said beam carrying a plurality of frequency channels,

comprising frequency channel allocating means for allocating each of said frequency channels to a group of said user stations which fall within one of a plurality of predetermined regions within the beam such that the variation in propagation delay to said satellite among said group of said user stations is limited, and means arranged to communicate with said user stations within said beam in said allocated frequency channels.

5. Apparatus as claimed in claim 4, including grouping means for determining said groups of said user stations such that each group comprises ones of said user stations which are approximately equidistant from said satellite.

6. Apparatus as claimed in claim 5, including position determining means arranged to determine the positions of the user stations relative to the earth's surface, the grouping means being arranged to determine said predetermined regions relative to the earth's surface.

The Patent Office

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Application No:	GB 9808386.8	**Examiner:**	Nigel Hall
Claims searched:	all	**Date of search:**	28 May 1998

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Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): H4L (LDRRS, LDRRX, LDC)

Int Cl (Ed.6): H04B 7/185, 7/19, 7/195, 7/204, 7/208; H04Q 7/36

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
	NONE	

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